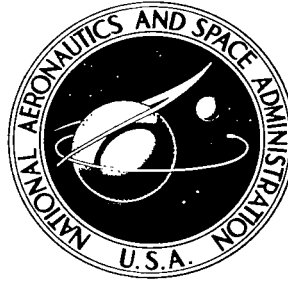


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CRITICAL HEAT FLUX FOR SATURATED POOL BOILING FROM HORIZONTAL AND VERTICAL WIRES IN REDUCED GRAVITY

by Robert Siegel and John R. Howell

*Lewis Research Center
Cleveland, Ohio*



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION - WASHINGTON, D. C. - DECEMBER 1965



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SUMMARY

Critical heat fluxes were obtained for water and ethyl alcohol boiling at saturation conditions from horizontal and vertical electrically heated platinum wires and for 60 percent by weight aqueous sucrose solution boiling from a vertical wire. The boiling apparatus was installed in a counterweighted drop tower that provided gravity fields ranging from approximately 0.015 to 1 times Earth gravity with test durations of about 1 second at the low gravities. As a rough approximation the critical flux decreased as $g^{1/4}$ except for a vertical wire in ethyl alcohol, where the critical flux decreased less rapidly than $g^{1/4}$. For vertical wires 1.5 and 3 inches long, the critical flux was found independent of wire length at both 0.015 and 1 times Earth gravity. At a fixed gravity field, a vertical orientation of the heated wire provided lower values for the critical heat flux than for a horizontal wire.

INTRODUCTION

Several applications have stimulated interest in boiling in gravity fields different from that on Earth. Heat-transfer equipment in space will be subjected to very low gravity fields, approaching zero gravity, on an orbiting or coasting vehicle. Reduced gravities of somewhat larger magnitude will result when the vehicle has a moderate acceleration. Gravity fields higher than Earth gravity will be present at vehicle launch, or in cooling applications for rotating machinery. Since this report deals with gravity effects on the critical (or peak nucleate boiling) heat flux, some of the references pertinent to this aspect of boiling will be reviewed.

The theory by Kutateladze (ref. 1), Zuber (ref. 2), and others has indicated that the critical heat flux depends on $g^{1/4}$. For the reduced gravity range, previous boiling experiments that provide information on the upper limit of nucleate boiling are summarized in table I and the data are shown in figure 1. The early experiments by Steinle (ref. 3) and Siegel and Usiskin (ref. 4) indicated that for conditions close to zero gravity the

TABLE I. - REDUCED GRAVITY CRITICAL HEAT FLUX BOILING STUDIES

Authors	Reference	Reduced gravity facility	Liquid	Test Section		Test duration, sec	Gravity range, g_e
				Material	Geometry		
Steinle	3	Drop tower, 9 ft high	Freon 114	Platinum	Horizontal wire, 0.0015 in. diam., 1.281 in. long	0.75	~ 0
Usiskin and Siegel	4, 5	Drop tower 9 ft high (counter-weighted)	Water	Platinum	Horizontal wire, 0.0453 in. diam., 2.5 in. long	0.75 for zero gravity	~ 0 to 1
Merte and Clark	6	Drop tower, 32 ft high (counter-weighted)	Liquid nitrogen	Copper	Sphere, 1 in. diam.	1.4 for zero gravity	~ 0.01 to 1
Sherley	7	Drop tower	Liquid hydrogen	Lead	Horizontal thin film, 2-sq. -in. area	1	~ 0
		Airplane	Liquid hydrogen	Lead	Horizontal thin film, 2-sq. -in. area	15	~ 0
Clodfelter	8	Drop tower, 55 ft high	Water	Platinum	Horizontal wire, 0.020 in. diam.; horizontal ribbons, 1/8 and 1/4 in. wide	1.85	~ 0.01
		Airplane	Water	Platinum	Horizontal wire, 0.020 in. diam.	3.5 to 7	< 0.01
Papell and Faber	9	Magnet	Colloid of magnetic iron oxide in normal heptane	Chromel	Horizontal ribbon, 1/16 in. wide, 1 in. long	Steady state	0 to 1
Lyon et al.	10	Magnet	Liquid oxygen	Platinum	Horizontal flat surface, 0.75 in. diam.	Steady state	-0.3 to 1
Siegel and Howell	Present study	Drop tower, 12.5 ft high (counter-weighted)	Water, ethyl alcohol, and 60 percent sucrose solution	Platinum	Horizontal wire, 0.020 in. diam., 1.5 in. long; vertical wire, 0.020 in. diam., 1.5 and 3.0 in. long	0.9 for zero gravity	~ 0.015 to 1

critical heat flux would be substantially decreased. The measurements by Sherley (ref. 7) showed that close to zero g , the critical flux had decreased to within the range of 0.5 to 0.7 of the value at $1 g_e$. The tests of Clodfelter (ref. 8), which were at fields less than $0.01 g_e$ yielded critical heat fluxes as low as 0.15 times the $1 g_e$ value. Only four publications have been available that report data where gravity has been varied over the range between 0 and $1 g_e$. Two of these utilized counterweighted drop towers. The data of Merte and Clark (ref. 6) fall quite well along the $g^{1/4}$ line down to about $0.03 g_e$. The measurements of Usiskin and Siegel (ref. 5) are somewhat above the $1/4$ power line in the range from 0.06 to $0.25 g_e$ (for simplicity only the two lowest burnout values have been plotted in figure 1 from their range of data at each gravity). The lowest g in reference 5 was listed as zero but was probably in the range between 0 and $0.01 g_e$ because of air drag on the falling platform of the drop tower.

The other two experiments covering the reduced gravity range (ref. 9) and (ref. 10) have utilized magnetic fields to partially or totally counteract the Earth's gravity field. With this technique steady-state experiments can be conducted in contrast with the short test times available with drop towers and aircraft. As shown in figure 1, the data from references 9 and 10 are substantially higher than the $1/4$ power line. This has led to the speculation by the authors in references 9 and 10 that in some instances nucleate boiling in a saturated liquid may not cease when the buoyancy force is reduced to zero.

Since the results for high gravity fields are less pertinent to the present study, they will not be reviewed in detail. Some typical experiments that have indicated an increase in critical flux approximately as $g^{1/4}$ are references 11 to 13. In reference 14 the burnout flux increased only slightly (i. e., at a much lesser rate than $g^{1/4}$) in the range from 1 to $10 g_e$ and then increased as $g^{1/4}$ for accelerations higher than $10 g_e$'s.

The present study provides critical heat flux information for saturated boiling in the reduced gravity range, and specifically examines the influence of test section orientation. The test section was an electrically heated platinum wire and was placed in both horizontal and vertical positions. The instability theory that predicts the critical heat flux depending on $g^{1/4}$ was based on the behavior of a vapor layer above an infinite horizontal surface and hence there is some question as to whether this would apply to a vertical orientation or cylindrical wire. In addition to studying the effect of test section orientation, the critical heat flux behavior in reduced gravity was compared for three fluids: water, ethyl alcohol, and 60 percent by weight aqueous sucrose solution. These three fluids were chosen because they exhibit different bubble behaviors in nucleate boiling. As shown in references 16 and 17, which were restricted to low heat fluxes, the departure of bubbles from the heated surface in water and ethyl alcohol is governed by buoyancy, while for sucrose solution the inertial force was dominating. The alcohol differed from water in that for alcohol, many more nucleation sites were active and the surface was covered with a denser population of small bubbles. It will be determined

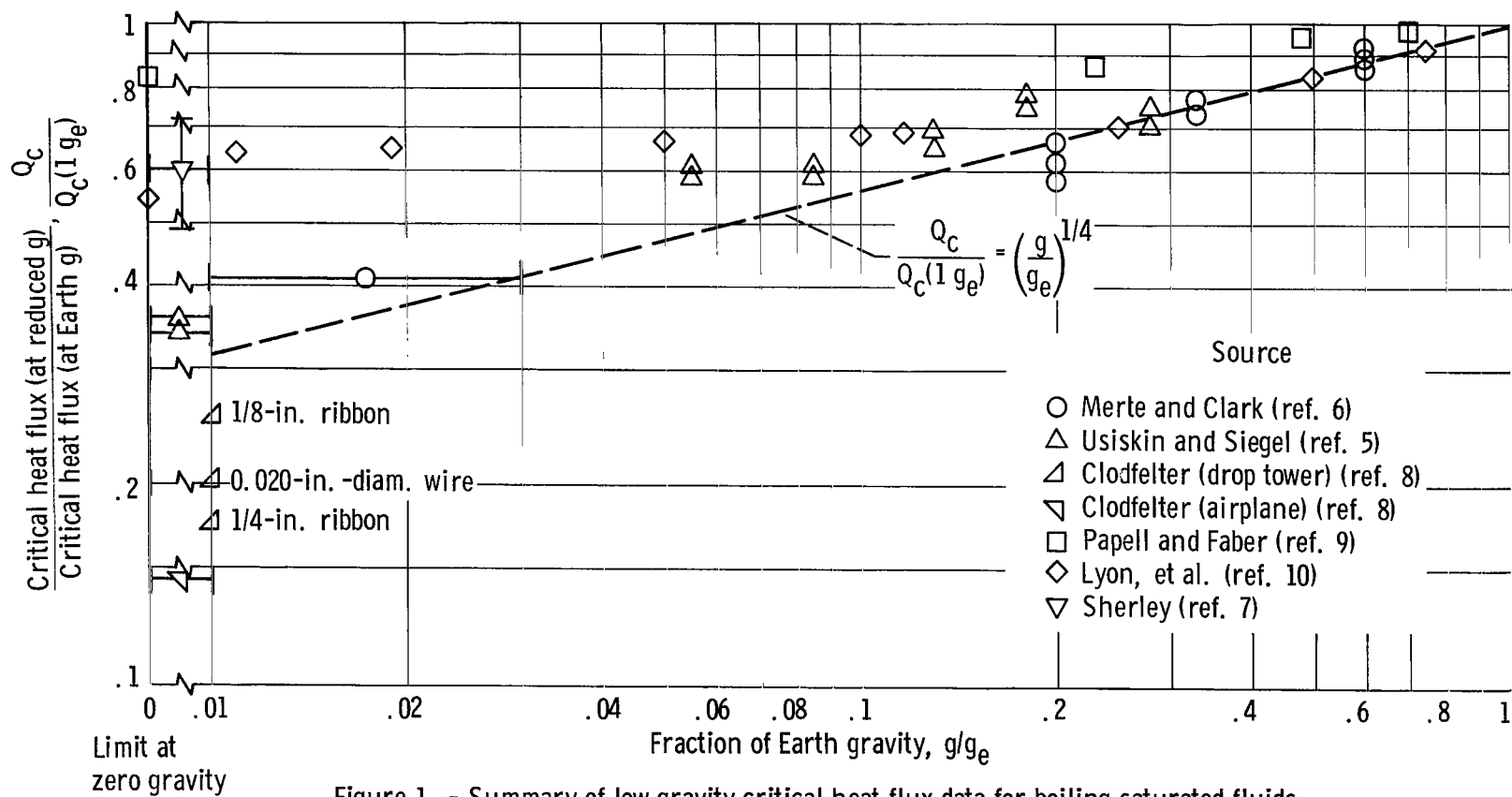


Figure 1. - Summary of low gravity critical heat flux data for boiling saturated fluids.

here whether the difference between inertia- or buoyancy-dominated bubble departure observed at low fluxes influences the gravity dependence of the critical heat flux for the reduced gravity range.

SYMBOLS

g	gravity field
g_e	Earth gravity field
Q_c	critical heat flux

EXPERIMENTAL APPARATUS AND PROCEDURE

Counterweighted Drop Tower

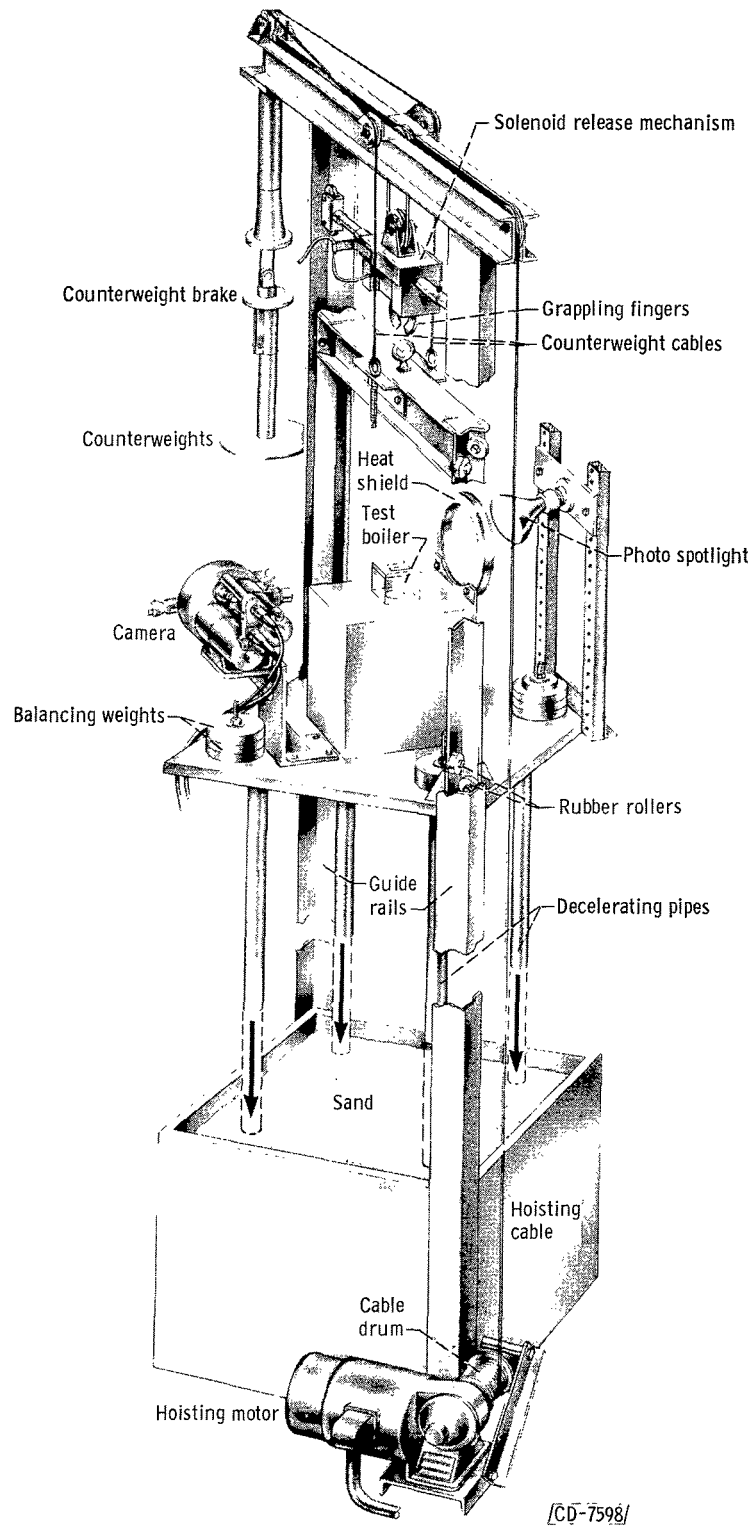
A drop tower, (fig. 2(a)) with a vertical fall of 12.5 feet was used to obtain reduced gravity fields for close to 1-second duration. The falling platform, on which the test boiler was mounted, could be counterweighted with various masses in order to regulate the effective gravity field. Because of friction in the platform guides and air resistance, the minimum gravity field obtained was about 0.015 times Earth gravity. Additional details about the drop tower, such as a description of the calibration to determine gravity field as a function of counterweight mass, are given in reference 15.

Test Boiler

The test boiler is illustrated in figure 2(b). A platinum wire 0.020 inches in diameter was suspended between two electrodes immersed in the test liquid. Horizontal and vertical wires 1.5 inches long were tested, and a taller glass enclosure was used to accommodate a 3-inch-long vertical wire. The liquid was maintained at saturation by auxiliary heaters along the sides and bottom of the tank.

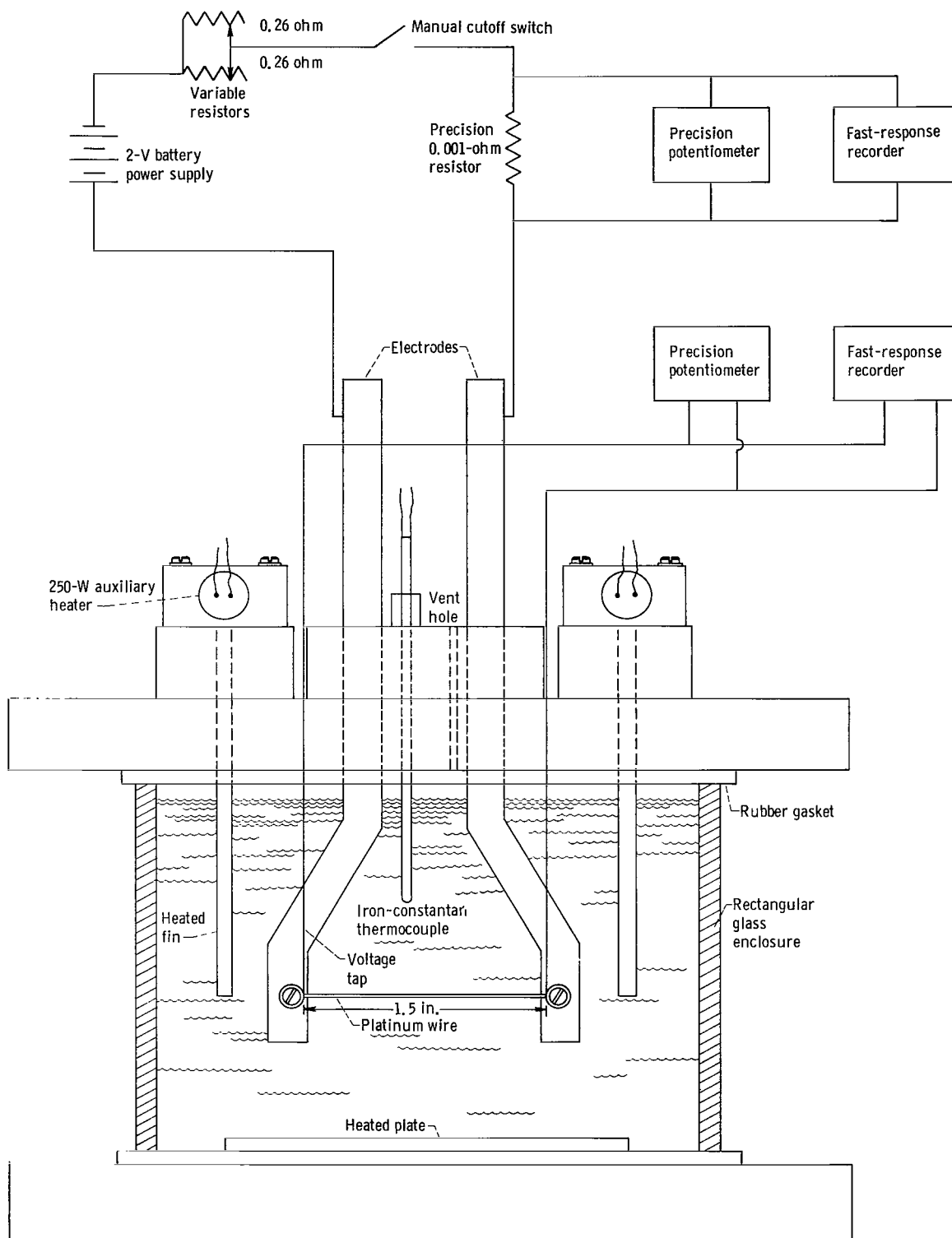
Instrumentation

The test wire was heated electrically by a bank of storage batteries. The power to the test section was regulated by a variable constantan resistor placed in series in the



(a) Counterweighted drop tower. (Drop height, 12.5 ft.).

Figure 2. - Experimental apparatus.



(b) Test boiler and instrumentation with electrically heated platinum wire shown in horizontal orientation.

Figure 2. - Concluded.

circuit as shown in figure 2(b). A precision 0.001-ohm resistor was also in series with the test wire, and the voltage reading across this resistor gave the current flow. Voltage taps at the ends of the test wire yielded the wire voltage drop. From the current, voltage, and dimensions of the wire, the heat flux was computed. For steady-state conditions the voltage signals were read with precision laboratory-type portable potentiometers. During the low gravity period, fast response ($\frac{1}{8}$ second for $4\frac{1}{2}$ -inch pen travel) recording potentiometers were employed. To be sure that the fluid temperature was at saturation, the temperature in the boiler was measured by two thermocouples, each encased in a stainless-steel sheath (one of these is illustrated in fig. 2(b)).

Procedure

The boiler was carefully cleaned and a test wire installed and wiped with ethyl alcohol. The test fluid was brought to its saturation temperature and allowed to boil in order to remove dissolved gases. The variable resistors were adjusted to provide a heat flux somewhat below the critical value in Earth gravity, the battery circuit was energized, and the fluid allowed to boil until the current and voltage readings were steady. After these readings were taken, the heat flux was raised about 5 percent and the readings repeated. This procedure was continued until the transition away from nucleate boiling began, and this gave a critical heat flux value for the Earth gravity condition. As soon as the transition began, the power to the test wire was shut off. The transition was detected by two means; the first was by visually noting a reddish glow, which began and started to spread from a small area of the wire. The second was by observing that the rapid increase in wire temperature at the critical flux produced an increase in wire resistance and an accompanying sudden increase in voltage drop. This transient was detected by a sudden unbalance of the galvanometer in the potentiometer measuring the voltage across the test wire.

After completing the test at Earth gravity, the platform on the drop tower was raised and the counterweight adjusted to provide the desired reduced gravity. The wire heat flux was adjusted to a value expected to be close to the critical flux for the reduced gravity, and the voltage and current readings were taken. Then the platform was released. The voltage and current signals were recorded during the reduced gravity duration; if the voltage across the wire showed a sudden increase, along with a simultaneous current decrease, then the heat flux was evidently above the critical value corresponding to that reduced gravity. If no change was noted on the recorders, then the flux was below the reduced g critical value (at least for the reduced gravity duration available with the drop tower). The flux was then raised or lowered about 5 percent, and the run repeated until values just above and below the critical flux were obtained. The

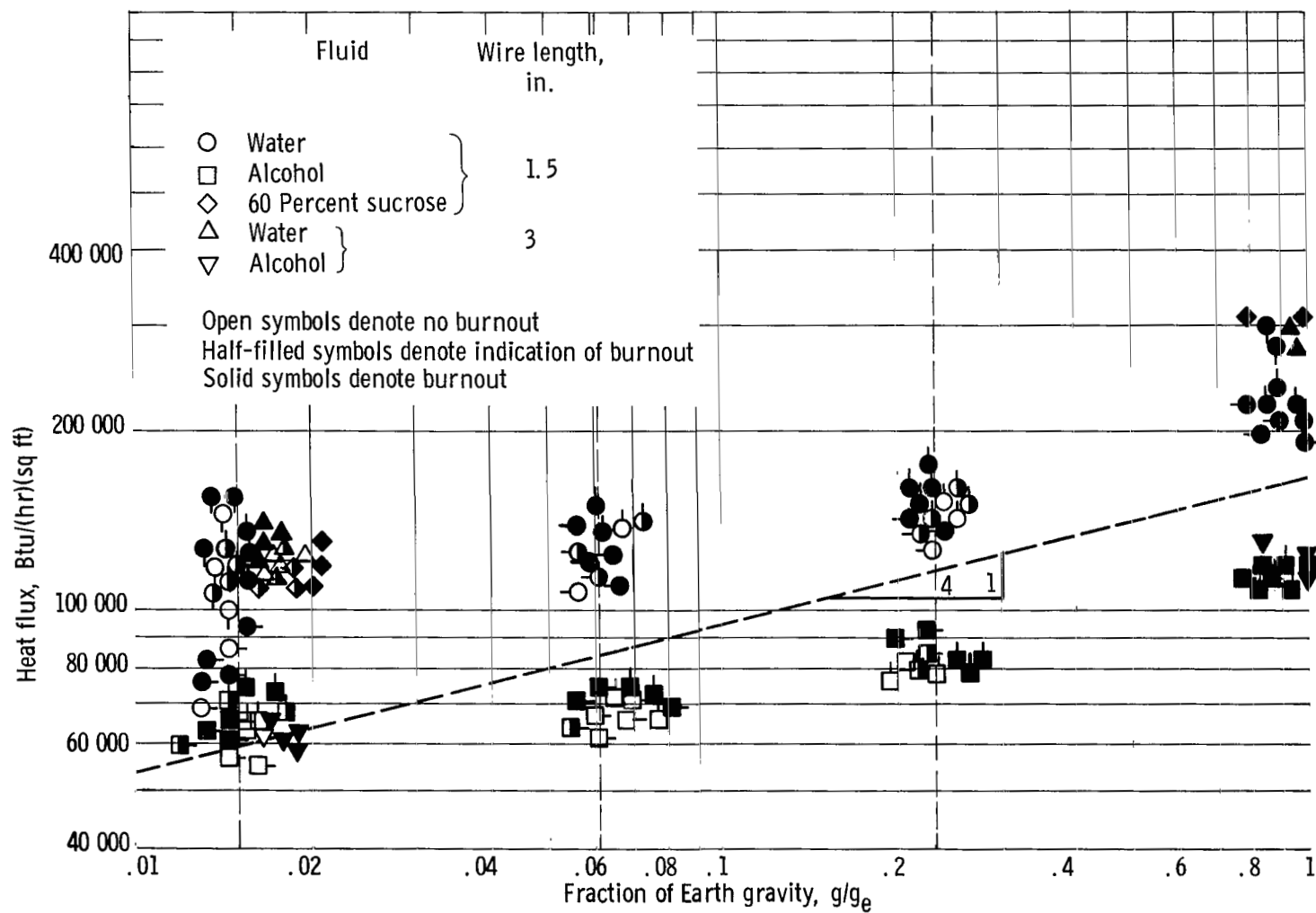
Earth gravity critical flux was checked again for comparison purposes. This procedure was repeated for three reduced gravities. Sets of data were obtained for a few different test wires in each of the horizontal and vertical orientations for water and ethyl alcohol, and for a vertical wire in sucrose solution.

The reproducibility of the data was found to be quite good. For ethyl alcohol the scatter was less than for water. This is probably caused by the fact that alcohol in nucleate boiling has the characteristic of having a greater number of active nucleation sites, which results in many small bubbles distributed rather uniformly over the surface, while water has large bubbles spaced further apart at more discrete site locations (see photographs in figs. 3 and 4 of ref. 16). Hence for water the way in which the nucleation sites are clustered contributes an additional variable governing the onset of transition away from nucleate boiling. For sucrose solution, data were taken for two conditions and had little scatter.

RESULTS

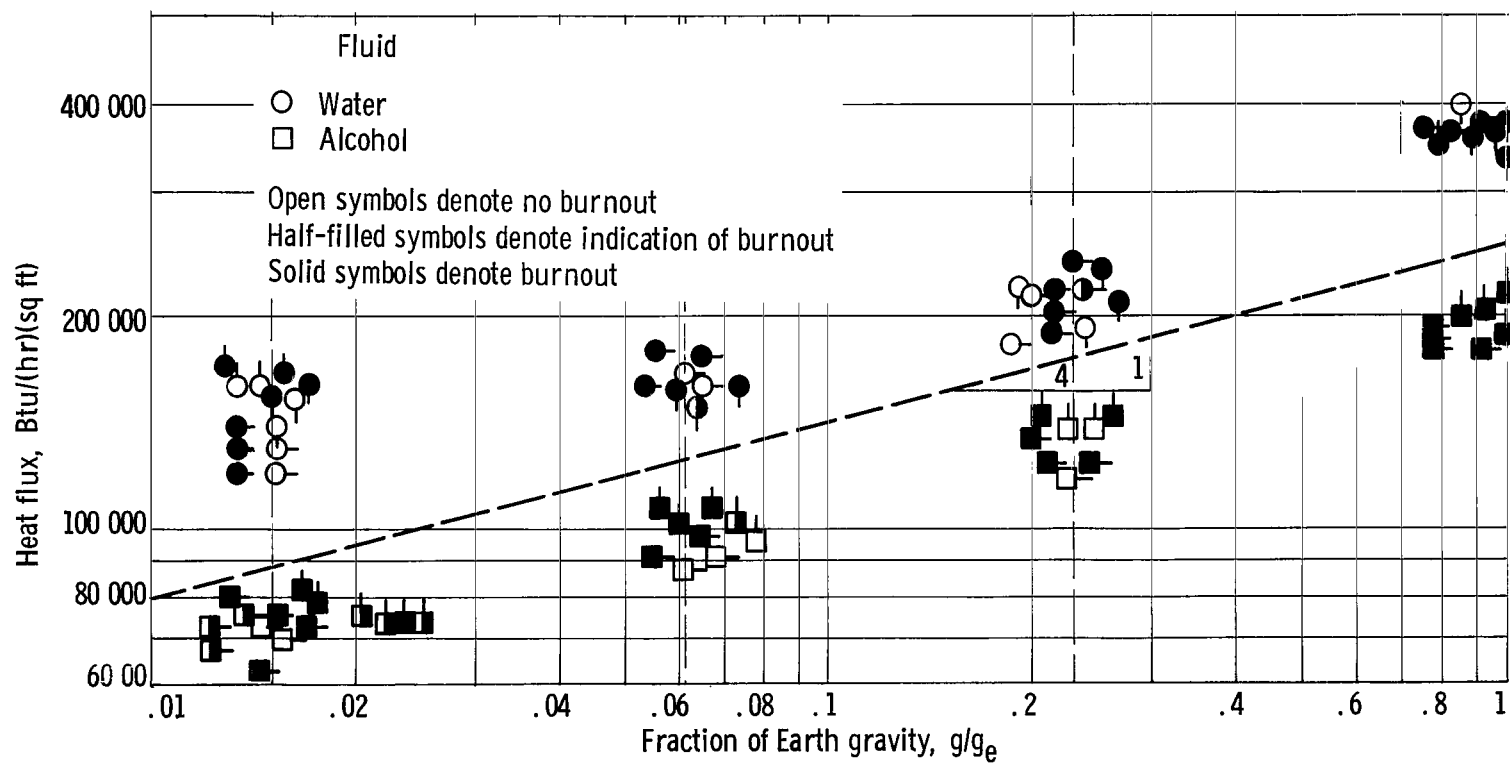
The experimental results are given in figures 3 to 5. Figures 3 and 4 give critical and near critical heat fluxes as a function of the fraction of Earth gravity. The data points that group together about each g were all taken at the same reduced gravity value. They are spread out horizontally because there are too many points to plot in a vertical row. The reduced gravities studied were 0.015, 0.061, and 0.23 times Earth gravity. From the calibration of the drop tower these gravities are known within $\pm 0.002 g_e$. Each set of data points that have the tail pointing in the same direction were taken using the same wire in a continuous sequence of runs where the apparatus was not shut down. In tables II to VI each wire number corresponds to such a sequence, and the data within each sequence are listed in the order in which they were taken. The open symbols in the figures denote heat fluxes at which no indication of burnout was present. The half-filled symbols indicate that the voltage and current signals deviated a little during the low gravity period, but there was some doubt as to whether burnout had really started. If a longer time in reduced g had been available, a definite burnout may have occurred. For the solid data points the critical heat flux was exceeded without any doubt. For simplicity, only the points where burnout definitely began are plotted in figure 4.

In figure 5 the ordinate is the ratio of the critical flux in reduced g to that in Earth g . To form this ratio each data point was divided by the $1 g_e$ critical flux measured for the same wire during the same consecutive set of tests. Only the points for which there was a definite indication of burnout are plotted.



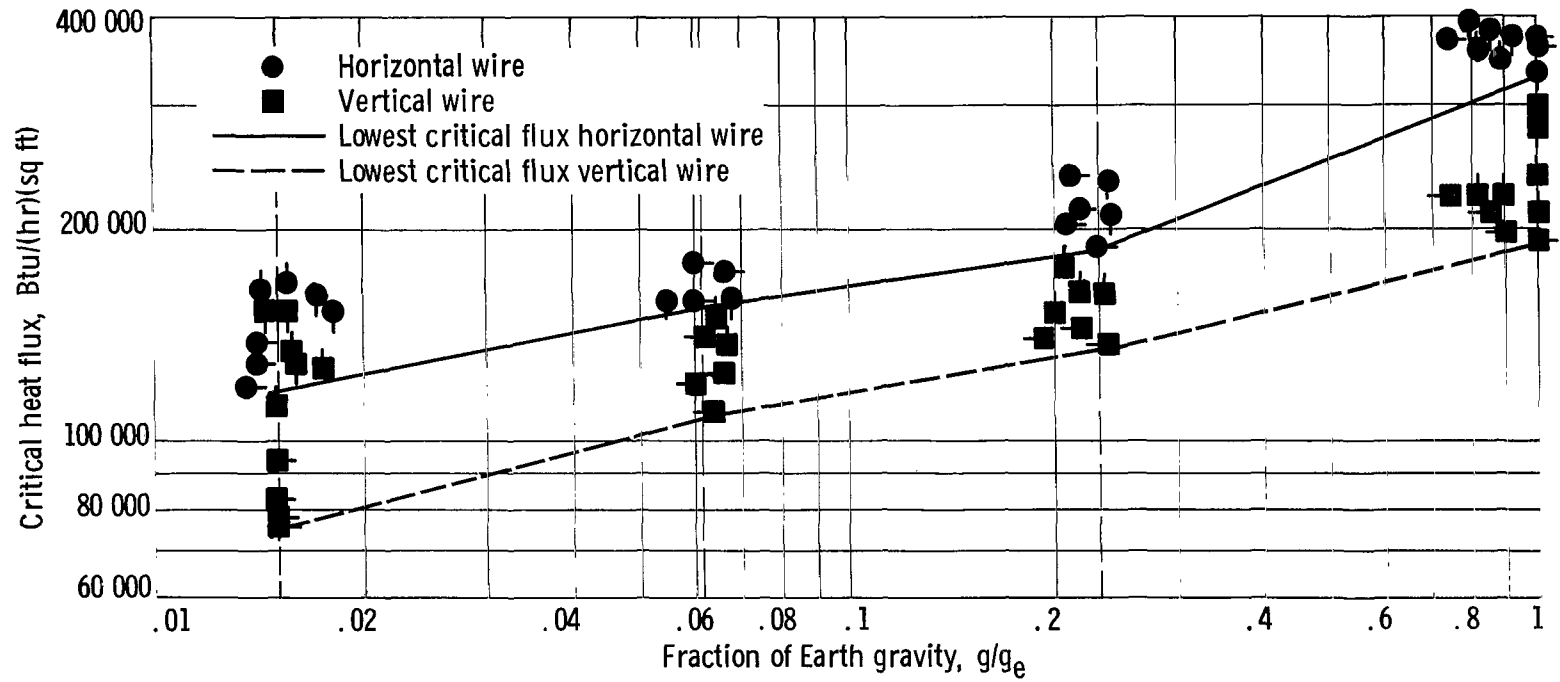
(a) Vertical wires. Wire lengths, 1.5 and 3 inches.

Figure 3. - Comparison of critical and near critical heat flux values for water, ethyl alcohol, and 60 percent aqueous sucrose solution for two vertical wire lengths and a horizontal wire as a function of gravity field. (Horizontal spread of data at each g/g_e does not represent a gravity variation but is for convenience in plotting the points.)



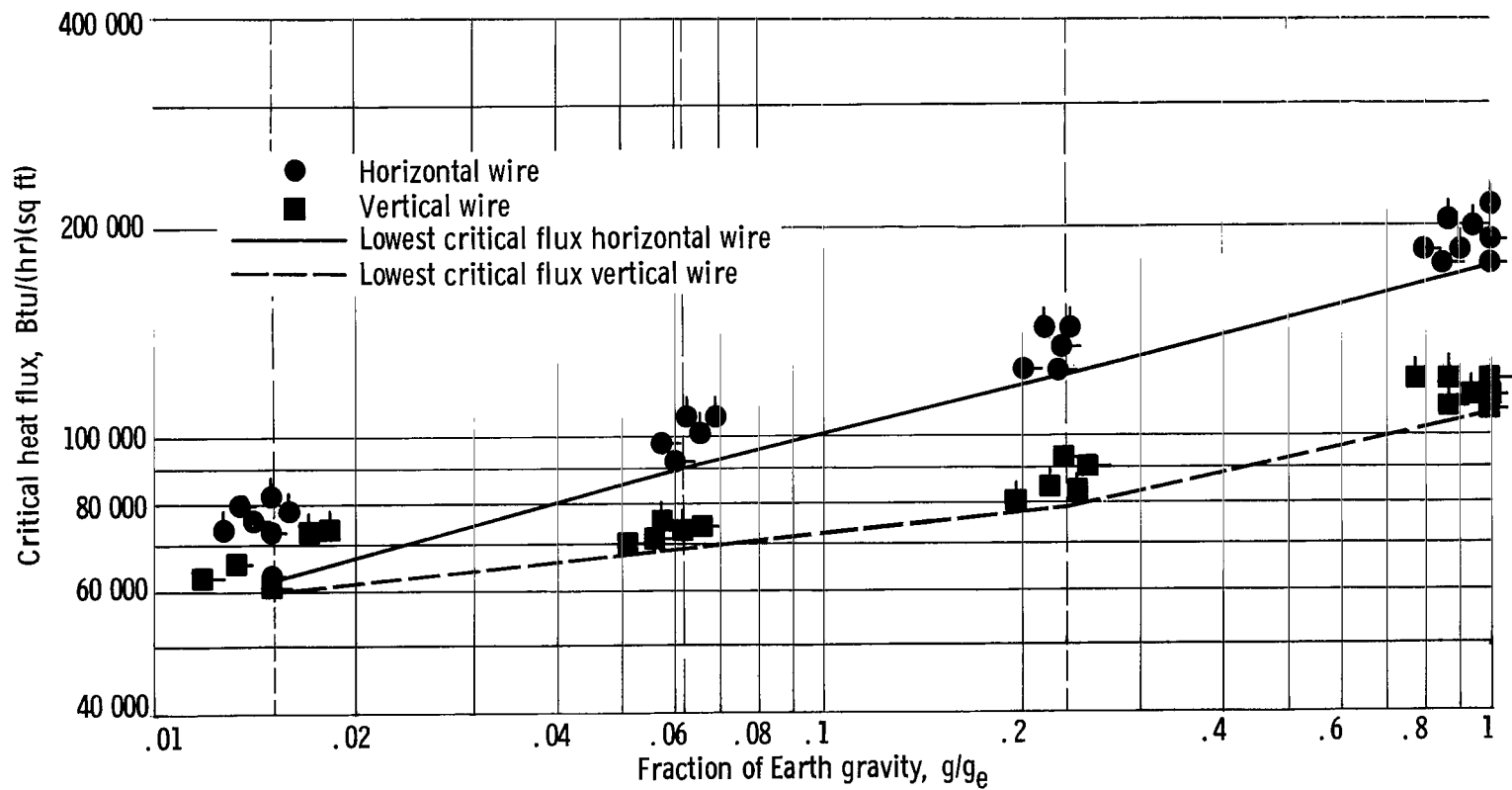
(b) Horizontal wires. Wire length, 1.5 inches.

Figure 3. - Concluded.



(a) Water.

Figure 4. - Comparison of critical heat flux values for horizontal and vertical orientations. Wire length, 1.5 inches. (Horizontal spread of data at each g/g_e does not represent a gravity variation but is for convenience in plotting the points. Only points where burnout occurred are shown.)



(b) Ethyl alcohol.

Figure 4. - Concluded.

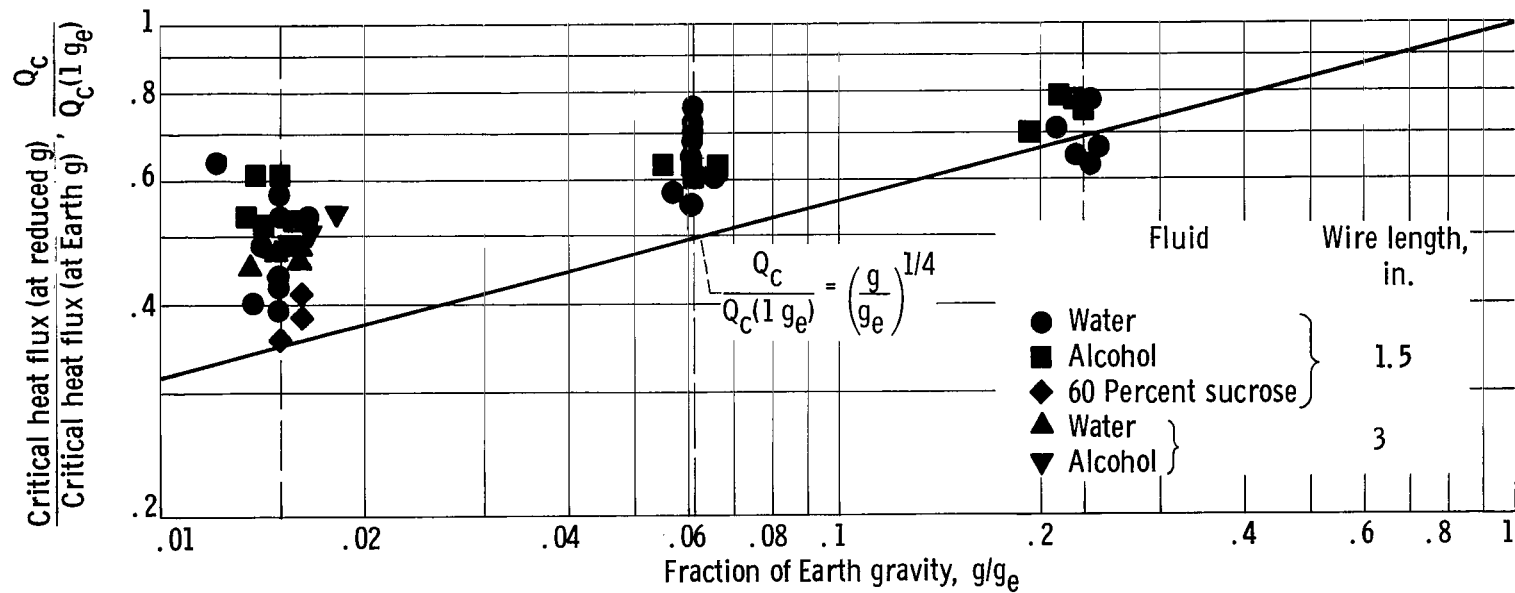
DISCUSSION

Figure 3(a) compares the critical heat flux behavior for water, ethyl alcohol, and 60 percent aqueous sucrose solution for wires in a vertical orientation. The trends for the three fluids are not much different except at the lowest gravities where the fluxes in alcohol drop off more slowly than for water or sucrose solution. The water and aqueous sucrose solution provided comparable critical heat fluxes at both 1 and 0.015 g_e . Within the statistical variations characteristic of critical heat fluxes, the change of wire length from 1.5 to 3 inches had no effect. Figure 3(b) shows that for a horizontal wire, water and ethyl alcohol have similar critical heat flux variations with gravity over the g range tested. Since the sucrose solution behaved the same as water for the vertical wire, it was not tested for a horizontal wire.

Figure 4 compares, for water and alcohol, the differences resulting from wire orientation. At the higher g values, the vertical orientation always gives heat fluxes substantially lower than the horizontal case. For water, as gravity is reduced, the vertical wire heat flux at each reduced gravity is still the same percentage below the horizontal wire value at the same reduced gravity. The difference in fluxes for the two orientations becomes much smaller, however, being about 42 000 Btu per hour per square foot at 0.015 g_e compared with 140 000 at 1 g_e . For ethyl alcohol, shown in figure 4(b), the percentage difference in critical flux decreases as g is reduced and at 0.015 g_e the horizontal and vertical orientations yield comparable values. The approach of the fluxes toward each other would be expected as gravity is reduced since the effect of orientation should vanish as gravity approaches zero.

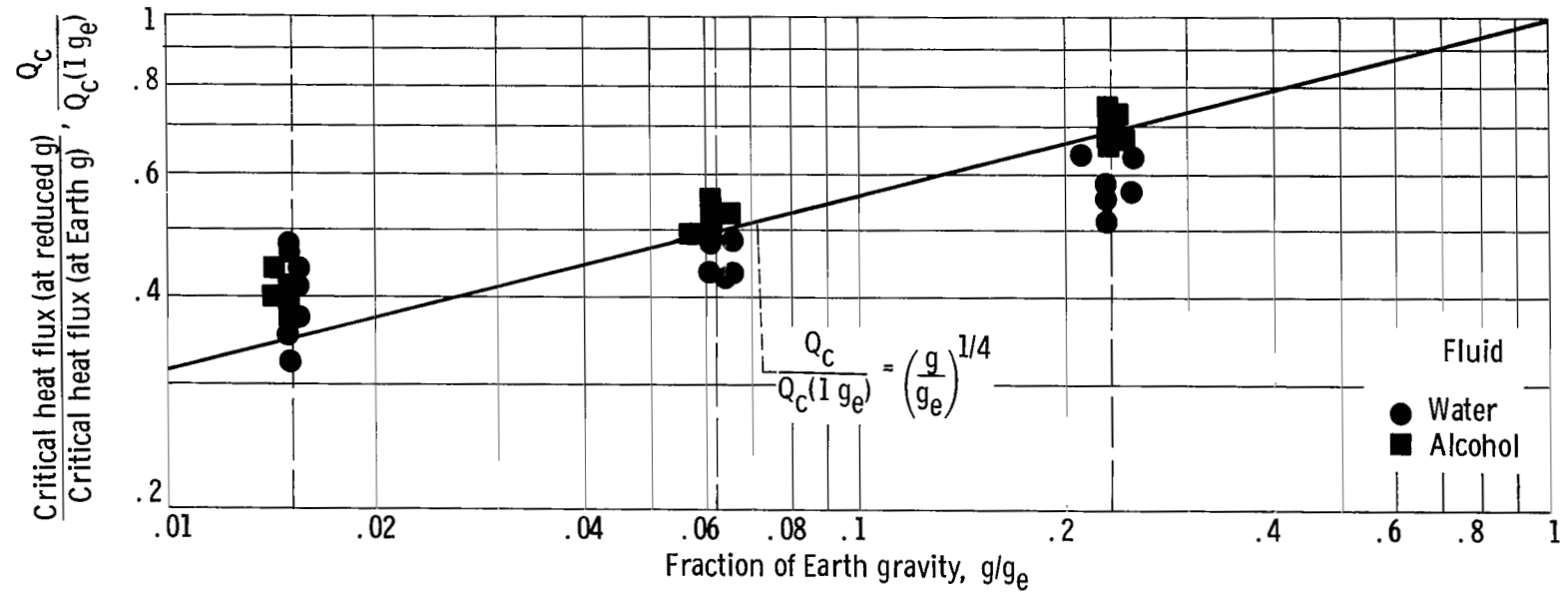
In figure 5 the ratio of critical flux in reduced g to that at 1 g_e is compared with the theoretical $1/4$ power variation. For a horizontal wire in ethyl alcohol or a vertical wire in water or aqueous sucrose solution, the lowest burnout points follow the theoretical line reasonably well. For the vertical wire in alcohol, the ratio drops off with a smaller slope than $(g/g_e)^{1/4}$. For a horizontal wire in water, the data at intermediate g values fall below the theoretical line.

The prediction of the critical heat flux based on instability theory utilizes a model where an interface between a liquid and a vapor layer is assumed to be normal to the body force. The vapor leaving the heated surface, and the liquid flowing toward the surface, are assumed to move in alternate columns. Referring to the present experiments, the motion of a vapor film around a heated wire is different for a vertical orientation than for the horizontal case. This is shown by the film boiling photographs (ref. 16) where in the vertical case the vapor moves upward along the heated wire and single bubbles do not detach as in the horizontal case. Hence, there is some question as to whether the presently available instability analysis still applies here. The fact that the data correlates to some extent along the $1/4$ power line does not prove the correctness



(a) Vertical wires. Wire lengths, 1.5 and 3 inches.

Figure 5. - Ratio of critical heat flux in reduced gravity to that in Earth gravity for heated vertical and horizontal wires in saturated water and ethyl alcohol and for vertical wire in sucrose solution. (Horizontal spread of data at each g/g_e does not represent a gravity variation but is for convenience in plotting the points. Only points where burnout occurred are shown.)



(b) Horizontal wires. Wire length, 1.5 inches.

Figure 5. - Concluded.

of the instability theory as the $1/4$ power relation arose originally by dimensional analysis (ref. 1).

The reason for testing 60 percent aqueous sucrose solution was that, at low heat fluxes, compared with water or ethyl alcohol it has exhibited a different departure behavior for bubbles leaving a heated surface in nucleate boiling. As shown in references 16 and 17 the bubble departure size in sucrose solution was not influenced by a gravity reduction to $0.014 g_e$, and the bubbles were found to be removed by the dynamic force associated with their growth. For water and ethyl alcohol, however, the bubble departure was dependent on the buoyancy force and was substantially influenced by the gravity reduction. In the present tests the effect on the critical heat flux of a reduction in gravity was the same for sucrose solution as for water and alcohol. Hence the critical flux in sucrose solution is a buoyancy dominated phenomenon, although the detachment of the nucleate boiling bubbles, as observed at low heat fluxes, is not. This indicates that the onset of film boiling for these wetting fluids is not governed by the bubble detachment mechanism itself, but by the removal of vapor, which may be attached or detached, from the general vicinity of the surface. This suggests that the onset of film boiling at the peak nucleate boiling flux depends on the condition where vapor simply cannot be removed from the vicinity of the surface rapidly enough.

The short duration of the drop tower tests introduces the possible influence of transient effects on the data. Since a time interval is required for the transition from nucleate toward film boiling to occur, a longer test duration would presumably tend to provide lower critical heat flux values in the low gravity range. Longer test times for near zero gravity have been obtained by using airplane flights, but these results have been somewhat inconclusive, possibly because of the large initial disturbances caused by the approach to the low gravity flight trajectory. A way of performing steady-state tests has been to use a magnetic field to oppose the gravitational body force (refs. 9 and 10). As shown by the data in figure 1 (p. 4), the critical fluxes using magnetic fields have been higher than those obtained with drop towers. Longer testing times on the drop tower would presumably make this difference even greater so that transient effects do not seem to account for the differences in the two types of data.

CONCLUSIONS

On the basis of the data presented here, in the range from 0.015 to 1 times Earth gravity, it appears that the $1/4$ power gravity dependence of the peak nucleate boiling heat flux can be used as a rough engineering guide. However, definite deviations from this rule occur for some of the data such as for a vertical wire in ethyl alcohol where the critical flux decreases less rapidly than $g^{1/4}$. At a fixed gravity field, a vertical

orientation of the heated wire provided lower values for the critical flux than a horizontal wire did. However, the critical fluxes in each orientation approached one another as the gravity field was reduced. Hence the direction of the buoyancy vector, as well as its magnitude, influences the critical flux.

The length of the test wires had no apparent effect on the critical flux in the vertical orientation for the lengths examined (1.5 and 3 in.). Critical flux must therefore be a localized effect governed by the accumulation of bubbles in the immediate vicinity of the wire. This is further substantiated by the fact that the critical heat flux for sucrose solution was found to be buoyancy dependent although nucleate bubble departure for this fluid observed at lower heat fluxes was previously shown to be independent of buoyancy. This indicates that the onset of film boiling for these wetting fluids may not be governed by the bubble detachment mechanism itself but depends on the condition where vapor (attached or detached) cannot be removed from the vicinity of the surface rapidly enough. The fact that more bubble interference would be expected for a vertical surface because of the rising of bubbles along the surface, may account for the lower critical fluxes in the vertical case.

The critical fluxes drop off more rapidly with gravity than those obtained during steady experiments using a magnetic field to counteract gravity. Since longer test durations in a drop tower would presumably lead to even lower critical fluxes, the transient nature of the present experiments does not seem to account for the difference from the magnetic field results.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 18, 1965.

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TABLE II. - PEAK NUCLEATE BOILING DATA FOR HORIZONTAL WIRES IN WATER

[Wire length, 1.5 in.; wire diameter 0.020 in.]

Wire number	Fraction of Earth gravity, g/g_e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication	Wire number	Fraction of Earth gravity, g/g_e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication
5	1	3.72×10^5	B ^a	7	1	3.52×10^5	B ^a
	.015	1.20	S		.015	1.64	N
	↓	1.30	N		↓	1.70	S
		1.38	S			1.61	N
		1.21	N		↓	1.65	S
		1.30	S		1	3.60	B
	1	3.64	B	8	1	3.78×10^5	B
	.061	1.67	N		.061	1.61	S
	↓	1.80	S		↓	1.49	I
		1.61	S		↓	1.59	S
		1.63	N		1	3.34	B
	↓	1.78	S		.23	1.94	N
	.23	2.15	S		↓	2.10	S
	↓	2.08	I		↓	2.22	N
		2.22	N		↓	2.36	S
		2.39	S		1	3.92	B
		2.05	S		1	3.71	B
	↓	1.90	S		.015	1.53	S
		1.83	N		↓	1.41	N
	1	3.68	B		↓	1.53	N
					↓	1.62	S

^aB: Burnout.

S: Strong burnout.

I: Indication of burnout.

N: No burnout.

TABLE III. - PEAK NUCLEATE BOILING DATA FOR VERTICAL WIRES IN WATER

[Wire diameter, 0.020 in.]

Wire number	Fraction of Earth gravity, g/g _e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication	Wire number	Fraction of Earth gravity, g/g _e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication
Wire length, 1.5 inches				Wire length, 1.5 inches			
1	1	1.95×10 ⁵	B ^a	4	1	2.24×10 ⁵	B ^a
	.015	.686	N		.015	1.14	I
	↓	.767	S		↓	1.21	I
		.778	S		↓	1.27	S
		.827	S		↓	1.14	S
		.872	N		↓	1.28	I
		.950	S		↓	1.37	S
					1	2.12	B
2	1	2.78×10 ⁵	B		.061	1.38	S
	.015	1.01	N		↓	1.38	N
	↓	1.08	I		↓	1.41	I
		1.18	N		↓	1.51	S
		1.27	S		.23	1.55	S
		1.46	N		↓	1.46	I
		1.55	S		↓	1.57	N
	1	3.02	B		1	1.64	S
3	1	1.97×10 ⁵	B		.23	2.19	B
	.061	1.26	I		↓	1.45	N
	↓	1.42	S		↓	1.51	I
		1.22	S		↓	1.60	I
		1.12	S		↓	1.78	S
		1.11	N		↓	1.61	S
		1.17	I		1	2.39	B
		1.25	S	Wire length, 3 inches			
	1	2.12	B	6	1	3.01×10 ⁵	B
	.23	1.37	I		.015	1.20	N
	↓	1.45	S		↓	1.28	I
		1.37	S		↓	1.40	S
		1.28	N		↓	1.24	N
		1.42	S		↓	1.30	I
	1	2.23	B		1	1.37	S
					.015	2.86	B
					↓	1.24	N
					↓	1.29	S
					↓	1.21	S
					↓	1.16	N

^aB: Burnout.

S: Strong burnout.

I: Indication of burnout.

N: No burnout.

TABLE IV. - PEAK NUCLEATE BOILING DATA FOR HORIZONTAL WIRES

IN ETHYL ALCOHOL

[Wire length, 1.5 in.; wire diameter, 0.020 in.]

Wire number	Fraction of Earth gravity, g/g_e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication	Wire number	Fraction of Earth gravity, g/g_e	Burnout flux, Btu/(hr)(sq ft)	Burnout indication
5	1	1.93×10^5	B ^a	8	1	2.01×10^5	B ^a
	.23	1.35	S		.015	.740	I
		1.18	N			.762	I
		1.25	S			.822	S
		1.25	S			.746	S
	1	1.79	B			.747	I
	.061	.890	N			.786	S
		.925	S		1	2.15	B
		.929	N		.061	1.08	S
		.990	S			1.01	S
	1	1.79	B			.985	N
	.015	.635	N			1.04	I
		.680	I			1.07	S
		.700	N		1	1.87	B
		.732	I		.23	1.38	N
		.761	S			1.44	S
		.736	S			1.39	N
		.736	N			1.46	S
		.771	I		1	2.05	B
		.805	S				
	1	1.86	B				

^aB: Burnout.

S: Strong burnout.

I: Indication of burnout.

N: No burnout.

TABLE V. - PEAK NUCLEATE BOILING DATA FOR VERTICAL WIRES IN ETHYL ALCOHOL

[Wire diameter, 0.020 in.]

Wire number	Fraction of Earth gravity, g/g_e	Burnout flux Btu/(hr)(sq ft)	Burnout indication	Wire number	Fraction of Earth gravity, g/g_e	Burnout flux Btu/(hr)(sq ft)	Burnout indication
Wire length, 1.5 inches				Wire length, 1.5 inches			
3	1	1.11×10^5	B ^a	4	0.23	0.80×10^5	S ^a
	1	1.15	B		↓	.766	N
	.015	.560	N		↓	.810	I
	↓	.617	S		↓	.833	S
	↓	.622	S		.061	.664	N
	↓	.553	N		↓	.726	S
	↓	.583	I		↓	.704	N
	↓	.630	N		↓	.735	S
	↓	.664	S		1	1.20	B
	.061	.623	N		.015	.654	N
	↓	.647	I		↓	.683	I
	↓	.676	N		↓	.735	S
	↓	.712	S		↓	.701	I
	↓	.656	N		↓	.738	S
	↓	.702	S		1	1.19	B
	↓	.708	N	Wire length, 3 inches			
	↓	.742	S	6	1	1.16×10^5	B
	.23	.843	N		1	1.27	B
	↓	.933	S		.015	.631	S
	↓	.847	I		↓	.627	N
	↓	.909	S		↓	.660	S
	1	1.21	B		↓	.615	S
					↓	.582	N
					1	1.31	B
4	1	1.11×10^5	B				
	.23	.794	N				
	.23	.834	S				
	1	1.13	B				

^aB: Burnout.

S: Strong burnout.

I: Indication of burnout.

N: No burnout.

TABLE VI. - PEAK NUCLEATE BOILING DATA
FOR VERTICAL WIRES IN 60 PERCENT BY
WEIGHT AQUEOUS SUCROSE SOLUTION

[Wire length, 1.5 in.; wire diameter, 0.020 in.]

Wire number	Fraction of Earth gravity, g/g_e	Burnout flux Btu/(hr)(sq ft)	Burnout indication
9	1	3.12×10^5	B ^a
	.015	1.09	I
	↓	1.19	I
		1.30	S
		1.11	S
		1.11	I
		1.19	S
		3.10	B
	1		

^aB: Burnout.

S: Strong burnout.

I: Indication of burnout.

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"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

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